

ANALYSIS OF PASSIVE COOLING AND HEATING POTENTIAL IN VIETNAM USING GRAPHICAL METHOD AND TYPICAL METEOROLOGICAL YEAR WEATHER FILE

Anh-Tuan Nguyen*, Sigrid Reiter

LEMA, University of Liège, Belgium

Address: LEMA, Bât. B52/3, Chemin des Chevreuils 1 - 4000 Liège; Email: natuan@ud.edu.vn*

ABSTRACT

This paper studies the potential to improve thermal comfort in Vietnam thanks to passive strategies. First, a thermal comfort zone for the Vietnamese is proposed by using the PMV-PPD heat balance model of Fanger and the effects of adaptive mechanism of the people living in tropical hot humid region. Then, the comfort zone is enlarged using the algorithms proposed by the authors to calculate the effects of the passive heating and cooling strategies. Typical Meteorological Year (TMY) weather data are used for graphically printing of hourly environmental parameters on the psychrometric chart and for climate analysis, subsequently. The limitation and the scope of this method are also specified. Results of this study show that in all climatic zones of Vietnam, natural ventilation is an efficient cooling solution, low-cost and easy to apply. Thermal comfort improvement of natural ventilation strategy varies with the climatic zones, increasing from 17.1% in Hanoi, 21% in Danang to 31.4% in Hochiminh city. Meanwhile, passive solar heating is not really effective since winter in Vietnam is usually not too cold and the capacity of the passive solar collector system is usually limited. Direct evaporative cooling also has a great cooling effect compared with that of natural ventilation, but significant humidity augmentation in the air in hot and humid conditions may be inappropriate. Seasonal analysis reveals that natural ventilation gives higher performance than other methods and is particularly effective in mild seasons. During 12 months in Hanoi, the analysis clearly shows significant contribution of natural ventilation in the period from April to October during which comfort period achieved might vary from 30% to 81%. The combination of all passive strategies considerably improves thermal comfort: 22.6%, 31.7% and 47.6% of total time in Hanoi, Danang and Hochiminh city, respectively. Finally, the findings of this study indicate that conventional heating and cooling methods are also needed during extreme weather conditions in summer and winter, especially in Hanoi.

1. INTRODUCTION

A full understanding of local climate is the main requirement for the designs of climate responsive architecture towards sustainable development. There have recently been some weather tools developed for climate analysis, but they are usually aimed to the application on people living in temperate climate and thus inappropriate when being applied to people living in hot humid climate. This study proposes a simple method for hot humid climate analysis with which the potential of comfort improvement of passive cooling and heating strategies in many regions of Vietnam is examined. In this analysis three typical sites, including Hanoi (21° North), Danang (16° North) and Hochiminh city (11° North), have been selected. They represent 3 climatic regions in the North, Centre and South of Vietnam.

The method proposed will be carried out through three steps: (1) proposition of an appropriate comfort zone for people living in hot humid climate; (2) printing of climate data and (3) quantitative analysis and assessment of heating and cooling potential of passive strategies.

2. COMFORT ZONE FOR PEOPLE LIVING IN HOT HUMID CLIMATE OF VIETNAM

There is still an argument that under a specific condition the comfort zone for different climatic regions is unchanged. Based on Fanger's study, ASHRAE [1] reported that under steady-state

condition, “people cannot *physiologically* adapt to preferring warmer or colder environments, and therefore the same comfort conditions can likely be applied throughout the world”. However, the comfort zone proposed by ASHRAE standard [2] seems to be inappropriate for Vietnamese since it neglects the adaptation to the humidity of people living in hot humid climate. Some computer weather tools also failed to predict comfortable period for the climate of Vietnam since they used inappropriate comfort boundaries. The comfort zone for Hanoi proposed by Climate consultant software [3] (using comfort model of ASHRAE standard 55) gives that only 4.9% of total time in a year should be comfortable, which is extremely low. Also in Hanoi, Fig. 1 shows the comfort prediction of another weather tool [4] in which Szokolay’s method [5] was adopted. The significant weakness of this method is that a steady-state condition was imposed, but the *adaptive comfort model* was employed to find neutral temperature. According to this prediction, only 2.5% of total time in a year is considered comfortable, extremely underestimating the real thermal environment.

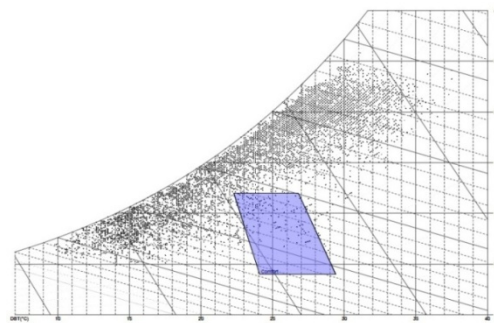


Figure 1: Incorrect prediction of comfort zone for Hanoi by weather tool [4]

The above analysis indicates that it is essential to create appropriate thermal comfort boundaries for Vietnamese considering the adaptation to humidity. This study proposes a thermal comfort zone for Vietnamese as shown in Fig. 2 using a steady-state thermal comfort model. This comfort zone, which is applied for a normal Vietnamese (height of 1.65m and weight of 60kg) in sedentary work (60W/m² – 1 met) and in still air condition (0.15 m/s), is established for 90% occupant acceptability. Clothing insulation values may vary from 0.5 clo (summer) to 1 clo (winter), reflecting the change of clothing style to suit seasonal weather.

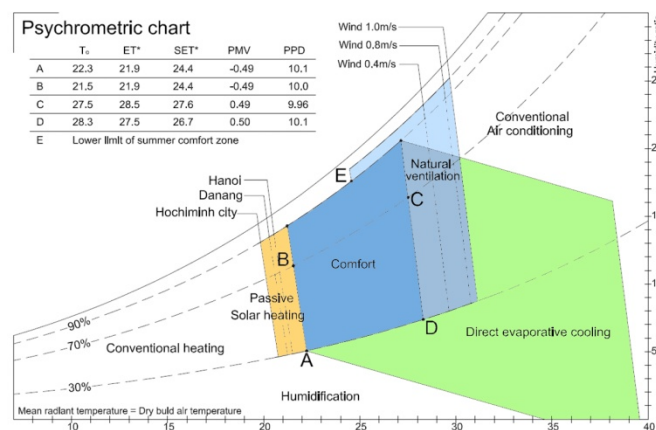


Figure 2: Comfort zone proposed for Vietnamese and its enlargements

The cooler and warmer boundaries of the comfort zone are defined by the PMV-PPD model ($-0.5 \leq PMV \leq 0.5$; $PPD \leq 10\%$). These boundaries are the lines AB and CD respectively (Fig. 2). Point B and C rely on 70% RH since PMV-PPD model is assumed to be inaccurate at RH higher than 70% [6]. These lines nearly coincide with the lines of constant ET*.

The lower humidity lever of the comfort zone was fixed at 30% relative humidity since it hardly falls below this value in humid climate and Vietnamese are not acquainted with dry nose, throat, eyes and skin caused by extremely dry air. The upper humidity limit is more complicated due to

lack of specific survey on this issue. ASHRAE [2] specifies an upper humidity ratio limit of 0.012 kg_w/kg_{dry air}. That is based on avoiding condensation and mold growth in the ducts of HVAC system [7] and hygienic conditions rather than on human thermal comfort requirements. Besides, in hot humid climate surface temperatures are closer to the ambient air temperature which is normally very high. This reduces the potential for condensation and mold growth, allowing the higher acceptable humidity limit in hot humid climate. Olgyay [8] proposed around 78% relative humidity as upper limit for U.S. moderate zones inhabitants. In his book, Givoni [9] suggested that upper limit could be enlarged to 90% relative humidity and up to 93% with ventilation. Pham [10] conducted a small comfort survey in Vietnam in 2002. His result revealed that over 80% of subjects found to be thermally comfortable at 28.5 – 29.5°C and 90% relative humidity. Adaptive comfort standards [2,11] even indicated that no humidity limit was required for thermal comfort. Based on above-mentioned studies and findings, the upper limit of comfort zone shown in Fig. 2 was fixed at 90% relative humidity. In summer, this humidity limit may be even enlarged to 95% under effect of a wind speed of 0.8 – 1m/s due to the effect of air change.

3. COMFORT CONTROL POTENTIAL ZONE BY USING PASSIVE COOLING AND HEATING STRATEGIES

3.1 Passive cooling by natural ventilation

Precise comfort improvement by elevated air speed has not been established. Both ASHRAE 55 [2] and ISO 7730 [6] recommend a maximum wind speed of 0.82 m/s for sedentary activity. However, this mainly bases on the requirement of stabilization of loose paper rather than human draught. It is not difficult to create thermal comfort for a person exposed to a wind velocity of 1 m/s [12] and under overheated conditions air velocities up to 2 m/s may be welcome [5]. The velocity of 1 m/s is, therefore, adopted in comfort enlargement shown in Fig. 2. Temperature offset above warmer limit of comfort zone by increased air velocity is strictly followed these two standards [2,6]. This enlargement neglects the effect of humidity on cooling potential of air movement since this effect is rather minor.

3.2 Passive cooling by Direct evaporative cooling

In direct evaporative cooling, water evaporates directly into the airstream, reducing the air's dry-bulb temperature and raising its humidity, but wet-bulb temperature is always unchanged. The total heat content of the system does not change, therefore it is said to be *adiabatic*. The cooling performance or leaving air temperature of the cooler may be determined:

$$T_{LA} = T_{DB} - (T_{DB} - T_{WB}) * \varepsilon \quad (1)$$

where

T_{LA} = Leaving air dry-bulb temp; T_{DB} = Inlet Dry-bulb temp; T_{WB} = Inlet Wet-bulb temp; ε = Efficiency of the evaporative cooler.

The cooler efficiency usually runs between 80% and 90%. Under typical operating conditions, an evaporative cooler will nearly always deliver the air cooler than 27°C. A typical residential 'swamp cooler' in good working order should cool the air to within 3°C – 4°C of the wet-bulb temperature [13]. Based primarily on previous experiment of other authors, Givoni [14] stated that ambient air can be cooled by 70–80% of the DBT-WBT difference. This observation led him to a comfort limit of ambient DBT of 42°C controlled by direct evaporative cooling. It is impractical to lower dry-bulb temperature more than 11°C by direct evaporative cooling [5], thus in Fig. 2, comfort zone was enlarged 11°C along wet-bulb temperature line.

3.3 Passive heating using Solar energy

This section will examine the lowest temperature at which the solar gain by the passive solar system (e.g. trombe wall system, massive masonry wall, south-facing glazing façade, sunspaces...) can match the heat losses of the building. Useful solar energy gained by a solar collector can be estimated on the following basis:

$$Q_u = A_c [I_t \tau \alpha - 24 U_L (t_p - t_a)] \quad (2)$$

where

Q_u = useful energy delivered by solar collector in a day, Wh; A_c = solar collector area, m²; I_t = Global solar irradiance, Wh/m².day; τ = transmittance, dimensionless; α = absorptance, dimensionless; U_L = overall heat loss coefficient, W/(m².K); t_p = average temperature of absorbing surface, °C; t_a = atmospheric temperature, °C

Some parameters in equation (2) are very difficult to identify. For convenience, equation (2) is empirically simplified using solar collector efficiency η (the fraction between useful heat distributed and total solar radiation falling on a solar collector system):

$$Q_u = \eta A_c I_t \quad (3)$$

According to ASHRAE [15], η can theoretically achieve maximum value of 0.82. For preliminary calculation, η is about 0.5. The limiting condition will be when the solar heat input equals the heat loss (ignoring heat loss caused by ventilation and infiltration):

$$Q_u = UA (t_i - t_a) * 24 \quad (4)$$

and then rearranging for t_a :

$$t_a = t_i - \frac{Q_u}{UA * 24} \quad (5)$$

where

U = building overall thermal transfer value (U-value), W/m².K; A = total building surface area, m²; t_i = lower limit of comfort temperature - indoor, K; t_a = atmospheric temperature at which thermal balance is achieved, K

Assume a standard building of 4.0x4.0x3.6 m with overall thermal transfer value (U) of 1.58 W/m².K; solar collector area (A_c) of 2.0 m² on the roof; t_i = 22.3°C at RH = 30% (see Fig. 3); total solar irradiance (I_t) (coldest month) of Hanoi, Danang and Hochiminh city are 2678, 3718 and 5161 Wh/m².day [16], respectively. Thus t_a for Hanoi, Danang and Hochiminh city are 21.51°C, 21.21°C and 20.78°C. These are lowest temperature at which heat delivered by a passive solar system can compensate for achieving comfort temperature.

4. CLIMATE ANALYSIS AND ASSESSMENT USING TYPICAL METEOROLOGICAL YEAR WEATHER DATA SET

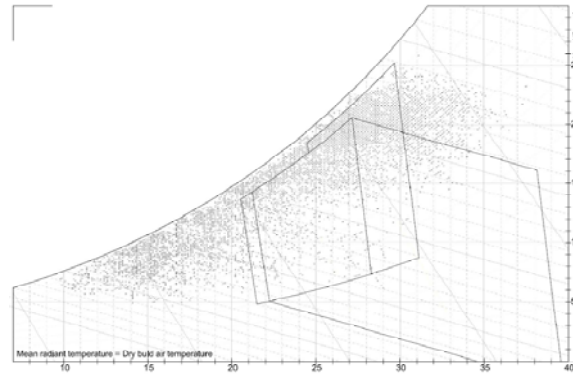


Figure 3: Hourly plot of Hanoi weather data on psychrometric chart

The TMY files for more than 2100 locations of the world can be obtained from the opened database of the U.S. Department of Energy [17]. A TMY data set provides users with a reasonably sized annual data set that holds hourly meteorological values for a one-year period that typify conditions at a specific location over a longer period of time, such as 30 years. Consequently, hourly weather data of any season, any month or any day can be separately printed out. In this step, hourly meteorological parameters of Hanoi, Danang, and Hochiminh city were graphically printed on the psychrometric chart (see Fig. 3) using TMY weather file. The comfort zone and its enlargements in Fig. 2 were then superimposed. All analysis and statistics were carried out on this two-layer psychrometric from which comfortable, potentially comfortable and uncomfortable period can be determined.

5. RESULTS

5.1 All year assessment

Fig. 4 shows the potential for comfort improvement of various passive cooling and heating strategies and their combinations. The weather in Hanoi is found to be naturally comfortable during only 23.6% of total time of a year whereas in Danang and Hochiminh city this value was around 32%, revealing that the climate of Hanoi seems more severe than the others.

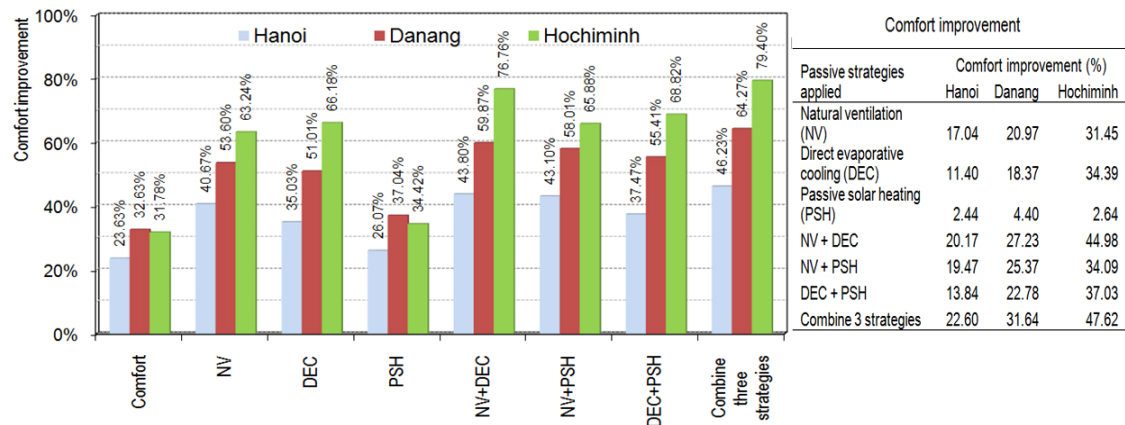


Figure 4: Potential of comfort improvement using passive heating and cooling strategies

In Hanoi, natural ventilation proves to be the most effective strategy for comfort improvement (17.04%). The combination of all strategies does not give considerable further improvement (22.60%). Maximum potential of comfort is only 46.23%, revealing that Hanoi mainly rely on many other solutions to obtain all year comfort. In Hochiminh city, natural ventilation is an extremely effective solution by which the comfort period can be doubled. Direct evaporative cooling is also a good promise since it may provide comfort for over 66% of total time. Nearly 80% of total time would be thermally acceptable if all strategies were combined, revealing that passive solutions must be considered as the first choice in building design in Hochiminh city. Danang is geographically located in the centre of Vietnam, consequently its climate in Fig. 4 is intermediate compared to those of Hanoi and Hochiminh city. In all cities, passive solar heating is not effective (comfort improvements were minor - smaller than 4.4%) due to much cloud cover as well as high average temperature in Vietnam in winter.

5.2. Four-season and twelve-month assessment in Hanoi

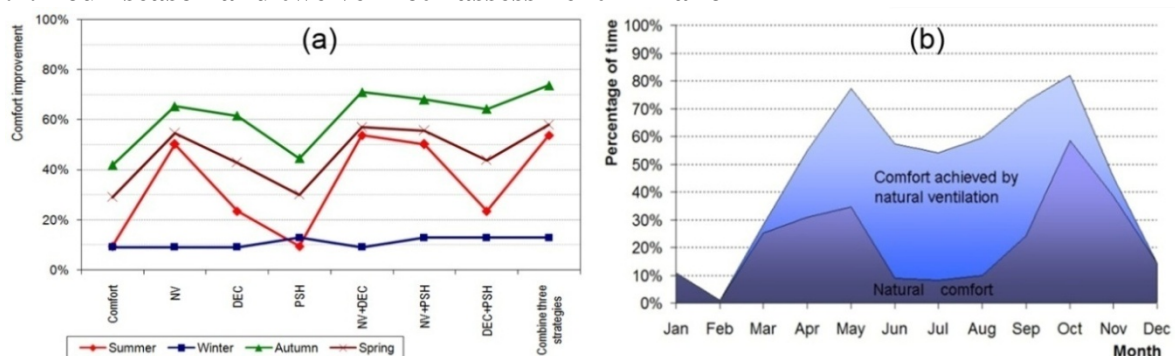


Figure 5: Comfort improvement (a) during 4 seasons and (b) during 12 months in Hanoi

A further analysis was carried out to examine the potential of comfort improvement of these strategies in each specific season and month in Hanoi. Fig. 5a shows that in winter, no strategy would be effective. In other seasons, natural ventilation would provide comfort at least of 50% of the total time. Combination of various strategies is not recommended as the effect is not noticeably higher. Comfort improvement during 12 months by natural ventilation is presented in Fig. 5b. According to this, natural ventilation is effective from April to the end

of September. The most effective period falls within summer (from June to the end of August), confirming that natural ventilation would significantly reduce cooling load. Maximum comfort occurs in mid-spring and mid-autumn. This figure also reveals that during winter natural comfort is extremely low (lower than 15%) due to the cold weather. Suitable heating solutions and building designs are therefore needed to keep indoor environment comfortable.

6. DISCUSSION AND CONCLUSION

In this study, natural ventilation and direct evaporative cooling almost have similar cooling effectiveness. Direct evaporative cooling requires sophisticated equipments and may raise the air humidity and mold growth on walls and clothes. Natural ventilation is low-cost, easy to apply and provides good indoor air quality but strongly relies on natural wind and building configuration as well as its location. Since Vietnam has hot and humid climate, natural ventilation in most cases would be the better choice for passive cooling because the increase of air humidity due to direct evaporative cooling is less appropriate for humid climates. The passive solar heating system does not have high efficiency since it can not store solar energy for nighttime heating. Active system with thermal energy storage and heat exchanger might perform better, even at night or under cloudy conditions. Relying completely on passive solutions to maintain human comfort is not feasible in Vietnam but there is a significant potential of comfort improvement.

This method has its own limitations as the TMY weather files are required for the analysis, but in current data resource they are available for only 2100 locations (1042 locations in the U.S.). For a certain location, weather file can be manually created using computer –aided tools (e.g. weather tool) with acceptable accuracy providing that sufficient input data exist. The method proposed in this paper can give reliable results and can be refined and applied by software programmers who focus on computer weather tools and building simulation tools.

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